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Daylighting, Dimming, and the Electricity Crisis in California

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Abstract

Dimming controls for electric lighting have been one of the mainstays of the effort to use daylighting to reduce annual lighting energy consumption. The coincidence of daylighting with electric utility peak demand makes daylighting controls an effective strategy for reducing commercial building peak electric loads. During times of energy shortage, there is a greatly increased need to reduce electricity use during peak periods, both to ease the burden on electricity providers and to control the operating costs of buildings. The paper presents a typical commercial building electric demand profile during summer, and shows how daylighting-linked lighting controls and load shedding techniques can reduce lighting at precisely those times when electricity is most expensive. We look at the importance of dimming for increasing the reliability of the electricity grid in California and other states, as well as examine the potential cost-effectiveness of widespread use of daylighting to save energy and reduce monthly electricity bills.

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Introduction

With rising energy prices and fluctuating supplies now a reality in California and other states as well, more effective strategies to reduce electricity demand in buildings are sorely needed. Lighting, which nationally represents 33% of the total electricity used by U.S. commercial buildings [1], is a major target for demand reduction. The use of effective lighting controls such as dimmable and daylight-linked systems can help to significantly reduce the amount of energy used by building lighting systems and offers major cost-management opportunities. Unlike most other major building loads, dimmable lighting systems can reduce electric demand in response to sudden increases in electricity costs, thus improving the elasticity of a building's demand profile. Furthermore, daylighting reduces energy use during peak demand times, thus saving energy when it is most expensive. In the context of California's energy crisis and the consequent increases in electricity rates, is daylighting now a cost-effective method to reduce demand? This paper will first provide an overview of electricity trends in California and then investigate the potential of daylight-linked controls to reduce peak demand and lower energy costs using a large San Francisco office building as an example.

Electricity Usage in California – the Big Picture

The electricity crisis in California and elsewhere has sensitized businesses and residences to the importance of using energy and electricity as wisely as possible. To understand the impact of this new awareness, it is instructive to compare the State's overall electricity usage in 2000, before the crisis became apparent, to the State's usage in 2001. The data plotted in Figure 1 shows the uncorrected California Independent Service Operator (ISO) electricity usage plotted by month for 2000 and 2001 [2]. (Approximately 20% of the State's electricity usage is not tracked by the ISO. Thus the ISO data does not include some municipal utilities as well electricity usage in the Northeast region of the State). The plot shows the statewide peak load for each month. The data shown has not been corrected for weather or economic activity. This comparison shows that peak demand averaged over the summer months (June through September, when demand is typically

highest) was 8.4% less in 2001 than in 2000. Also important is the obvious reduction in the monthly maxima. For example, in June 2000, the monthly maximum was about 43,000 Megawatts while in June 2001, the maximum never exceeded 40,000 Megawatts. Other analysis (data not shown) indicates that while the load exceeded 40,000 Megawatts nearly 10% of the time during June 2000, it was never exceeded during June 2001. This reduction in the maximum demand is of crucial benefit for power-strapped utilities, since the cost to provide additional power goes up exponentially when demand is already high. This positive trend helped to minimize the impact of peak demand use during the critical summer months.

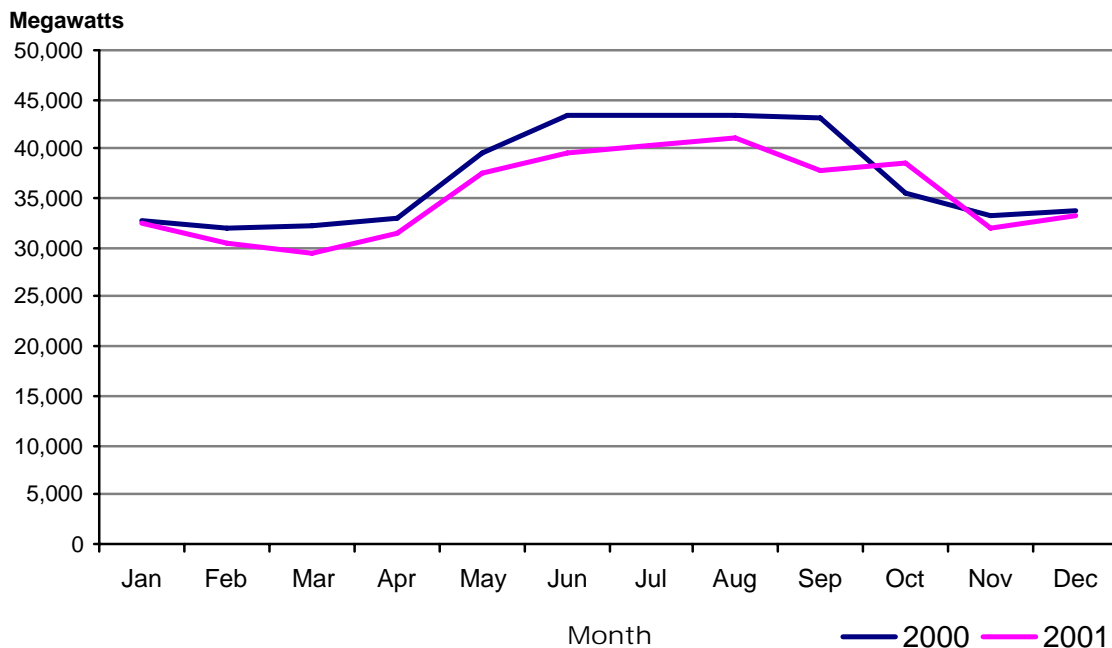


Figure 1. Peak California ISO demand for 2000 and 2001.

Since the State's electric load is known to be somewhat sensitive to weather, it is important to compare temperature data to account for its possible influence on peak demand. A recent LBNL study by Goldman et al. (2002) shows that the summer temperature data for both 2000 and 2001 were in fact "almost indistinguishable" [3]. Furthermore, the study reports that data published by the National Climatic Data Center indicates that summer 2001 was the 19th hottest summer in 107 years (NCDC, 2002). Given the similarities in temperatures between the two years, the reduction in electricity usage in 2001 cannot be explained away because of weather effects.

One of the most challenging tasks for today's electricity providers is supplying sufficient electrical power when the weather is hot throughout the State. Data plotted from the CEC [4]

provides a picture of the State's electricity usage on the hottest day in 1999. Figure 3 shows the electrical demand in the residential, commercial, industrial and agricultural sectors, hour by hour, for this hot summer day. Note that while the commercial building sector's electricity demand peaked at around 2:00 pm due to the high use of air conditioning, the residential sector did not peak until about 6:00 pm. The net effect of this overlapping of electricity usage in residential and commercial buildings is an extended peak of four hours duration (2:00 pm - 6:00 pm). A long, sustained peak such as this is a heavy burden on electricity providers. On days like this, any reduction in electric demand is of the greatest economic value to utilities.

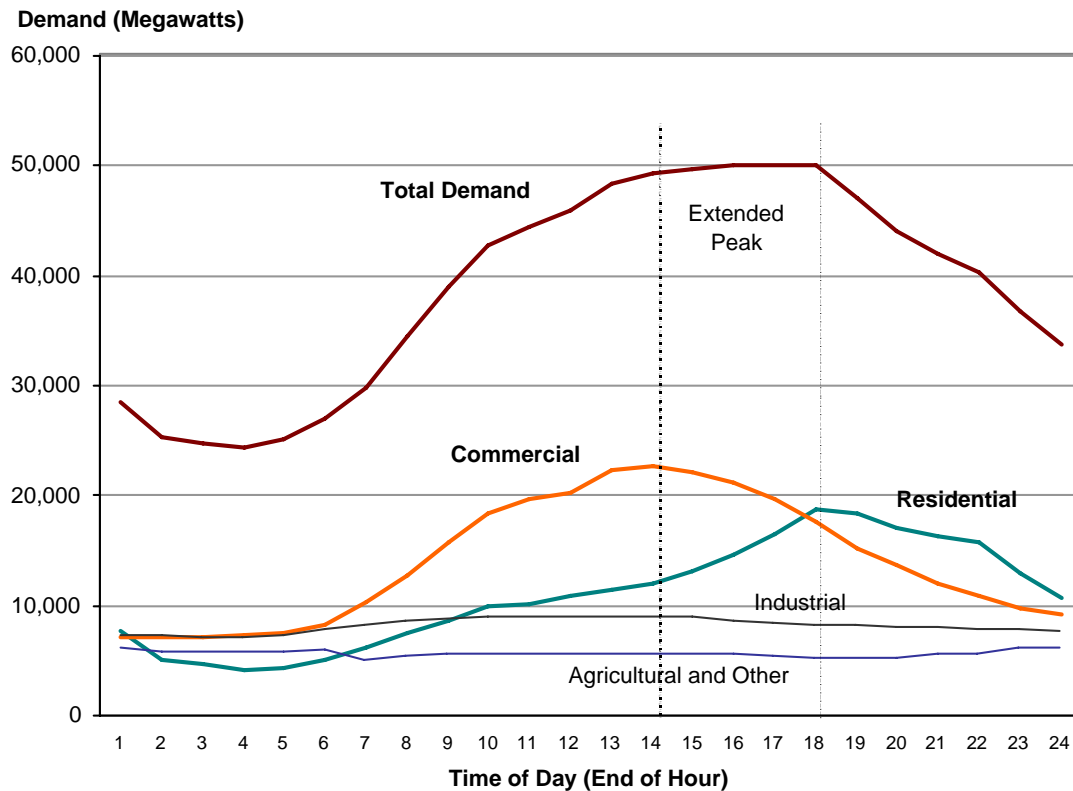


Figure 3. Total California load profile for a hot day in 1999. Commercial buildings peak at 23,000 megawatts at 2:00 pm while residences do not peak until about 6:00 pm.

This graph emphasizes the importance of control strategies such as daylighting that relieve electricity demand by reducing commercial energy use during peak times.

Electricity Usage in the San Francisco Federal Building

The preceding discussion has provided a picture of historical electricity usage for most of California. In the following sections, we focus on the historical electricity usage in one large California office building in San Francisco. We selected the Philip Burton Federal Building for our example since we have detailed monthly electricity bills for this complex going back to 1999

and, as a building, it is reasonably representative of older, large office buildings in the temperate San Francisco area. Furthermore, previous research at this site [5, 6] enabled us to measure the realistic impact of daylighting in representative portions of the building. The availability of extensive end-use data from these previous studies made the Federal Building a good candidate for our current analysis of the cost-effectiveness of daylighting.

The SF Federal Building houses multiple federal agencies and occupies a full city block. Each of its 21 stories has an area of 60,000 ft² (6,000 m²), for a total building area of 1.4 million ft² (140,000 m²). As only 21% of the gross area can be effectively daylit, the building was obviously not designed with daylighting in mind.

As seen in the following graph, the electricity consumption at the Federal Building remains relatively constant throughout the year. This implies that air conditioning—typically the largest load in commercial buildings—is not significantly higher during the summer than during the winter, which makes sense for a city with a moderate climate, such as San Francisco.

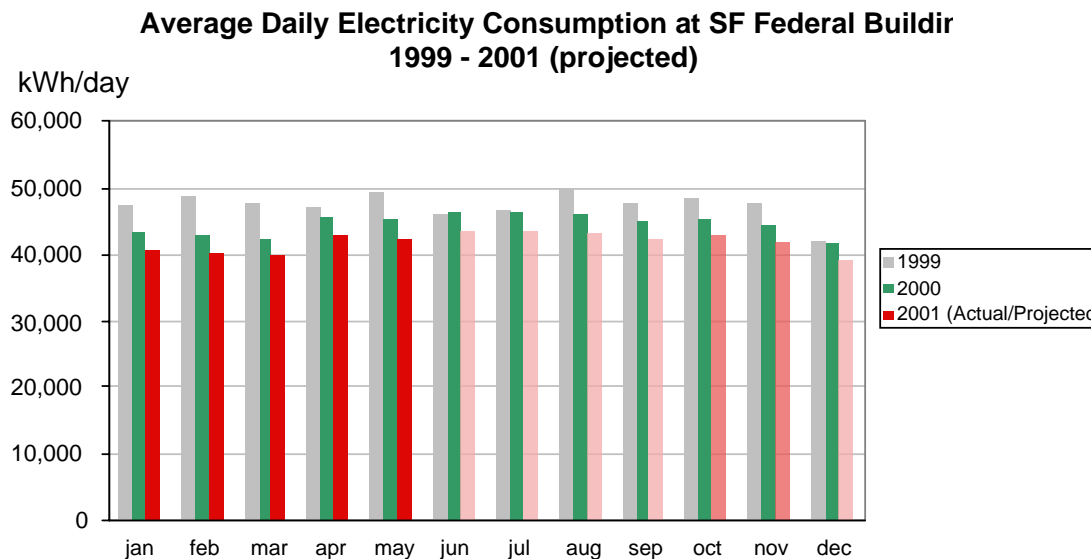


Figure 4. Historical electricity consumption at the SF Federal Building expressed as average daily electricity consumption for 1999, 2000 and through May, 2001. Data for June - December 2001 are estimates based on assumption that earlier reductions would continue through the end of the year.

An examination of the year-on-year differences reveals that overall electricity use at this building was consistently about 6% lower in 2000 than it was in 1999. In February and March 2000, the daily average electricity consumption was over 10% lower than in the previous year. This reduction in electricity usage is particularly notable because it predates the public awareness of the California electricity crisis. Long before news of the energy crisis hit the media at the end of

2000, the GSA was already significantly reducing its electricity usage in this major facility. The majority of the energy savings is most likely attributable to the completion of lighting retrofits throughout the complex [7], which replaced magnetic ballasts and T-12 fluorescent lamps with electronic ballasts and T-8 lamps.

The reductions in 2001 (we only have metered data through May 2001) were also impressive - average daily consumption was 4.6 - 7% lower in 2001 than in 2000.

Effect of New Rate Structure on Electricity Costs

The previous section described how the electricity usage at the SF Federal Building has steadily diminished over the last three years. The upcoming section analyzes how the new utility rate structure adopted by the California Public Utilities Commission (CPUC) in June 2001 will affect how much the Federal Building pays for electricity.

The rate structure used by most California utilities for charging their large commercial customers for electricity is based on the sum of two components -- a time-of-use rate and a demand charge. The time-of-use rate charges for electricity are based on the time of day that the electricity is being used. In the summer months (Figure 5a), the weekday rates are divided into three subsets: an on-peak rate (noon - 6 pm), a partial-peak rate (8:30 am - noon and 6:00 pm - 9:30 pm), and an off-peak rate (all other times). In the winter months (Figure 5b), only an off-peak and a partial-peak rate are applied. The new rates (red lines in Figure 5) became effective June 2001. Note that during the summer, the on-peak rate went from about 6¢/kWh to over 15¢/kWh.

The demand charge is a surcharge that is proportional to the maximum electricity usage of any 15-minute period during the month. This number is then multiplied by a rate (\$11.80/kW in the summer and \$2.65/kW in the winter) to calculate the demand charge for the month. (Note the listed values for the demand charge and the time-of-use rates plotted in Figure 5 are for buildings on the E20P rate schedule. The E20P schedule is used for very large buildings, with total electrical demand exceeding 1 Megawatt). While the time-of-use rates increased significantly as of June 2001, the demand charges have not changed.

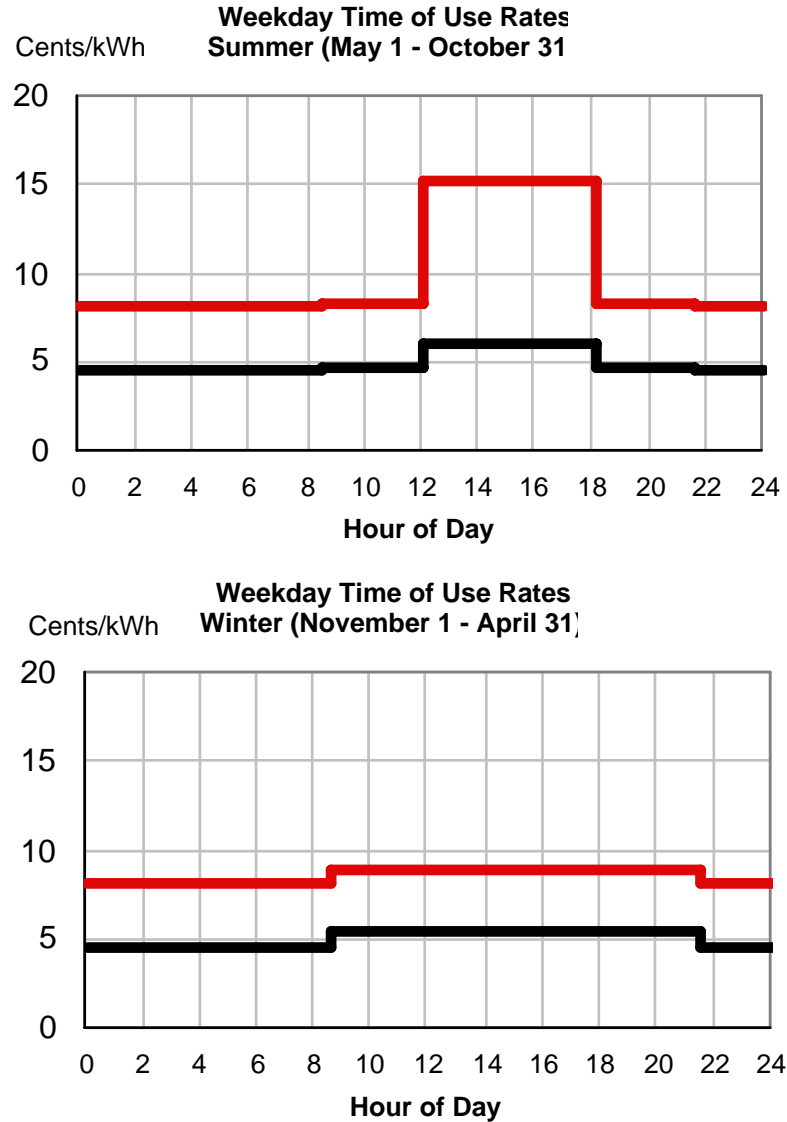


Figure 5. Old and new time-of-use rates for commercial buildings on the E20P rate schedule. The red line in (A) shows the weekday time of use rate for summer (May 1 - October 31) effective June 2001 while the black line shows the old rate in effect before January 2001. (B) shows the time of use rates for the winter (November 1 - April 31).

Before analyzing what fraction of the monthly electricity bill is due to the time-of-use rate as opposed to the demand charge, we present the total electricity bills for the Federal Building for 1999 through May 2001 (Figure 6 below).

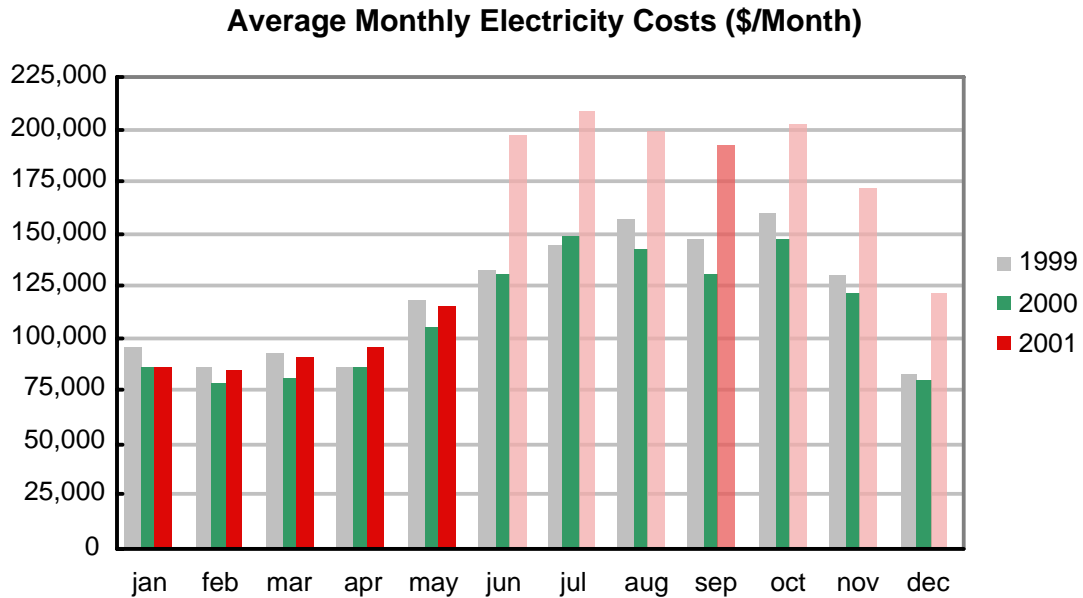


Figure 6. Total monthly bills for the SF Federal Building, 1999 through May 2001. Values for June through December 2001 are estimates based on the assumption that the energy savings evident in January through May 2001 can continue for the remainder of the year.

Two trends are evident in Figure 6. First, while the consumption of electricity is relatively constant over a year, the building pays nearly twice as much for its electricity during the summer than it does during the winter. Second, although considerably less electricity was used in early 2001 as compared to the same period in 2000, the monthly bills in 2001 are slightly higher. This is due to the effect of a 1¢/kWh increase of electricity rates that was imposed across the board by the CPUC in January 2001.

The startling increases in monthly electricity bills projected after May 2001 are attributable to rate increases imposed in June 2001.

How much of the monthly electricity bills throughout the year is attributable to the demand charge, and how much to the time-of-use rate charge? To answer this question, we examined the detail of the Federal Building electricity bills, which break down the monthly bill into 4 bins: the three time of use rates (two during the winter) and the demand charge. Figure 7 portrays this breakdown for year 2000 as a stacked bar chart. Note that in 2000, the summer demand charges accounted for nearly 50% of total monthly electricity bill, while time-of-use costs fluctuated little over the year. Thus, it was primarily the demand charges that caused the bills to be so much higher in the summer.

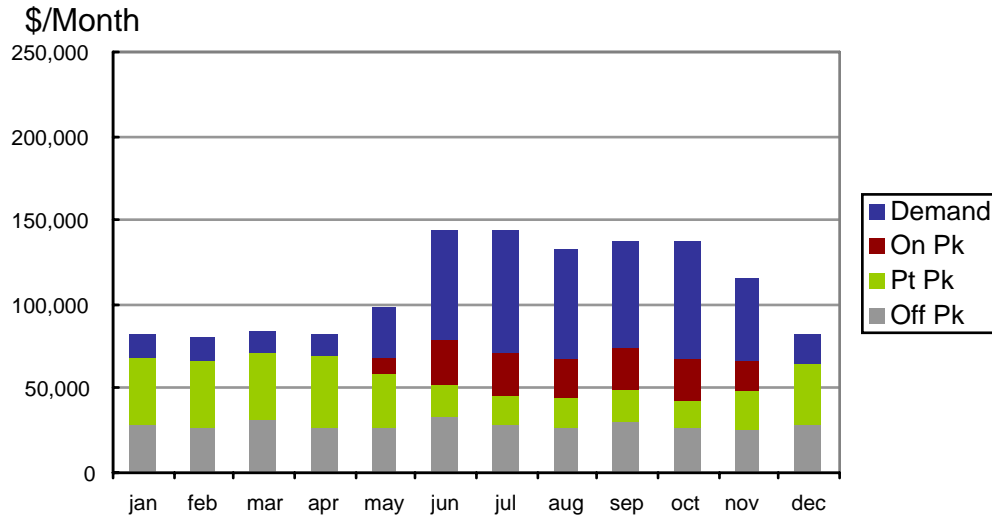


Figure 7. Monthly bills for the SF Federal Building for year 2000, broken down according to use category.

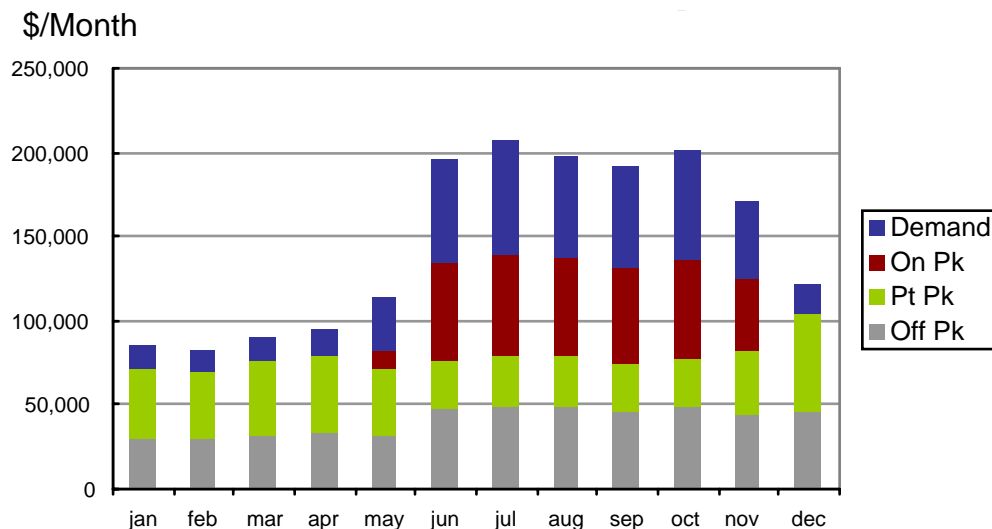


Figure 8. Monthly bills for the SF Federal Building for year 2001, broken down according to use category. Values for June through December are estimates.

Figure 8 shows the same monthly charge breakdown for 2001. While electricity was typically about \$150,000/month in 2000, the rate increases will raise those summer bills to closer to \$200,000/month in 2001 -- a very significant increase in energy costs. With this year's significant increase in time-of-use rates, the time-of-use portion of the electricity bill will account for a larger fraction of the monthly charges in 2001 than in previous years. Since the rate increases imposed in June 2001 are expected to be semi-permanent, the Federal building can also expect to pay higher costs for electricity during the winter months (closer to \$120,000/month) for the foreseeable future.

Potential of Daylighting Dimming Systems to Reduce Demand

We wanted to investigate the economic effectiveness of installing daylighting controls to decrease the electricity demand of the Federal building. We looked specifically at the economics of applying daylight-dimming controls to all perimeter lighting in this building (essentially the outer two rows of lights for all stories). We used the measured lighting power data from our daylighting tests on the 3rd floor in 1997 [6] to estimate the demand reduction for different times of day and year, then calculated the effect of perimeter daylight dimming on monthly energy use and costs using the new rates.

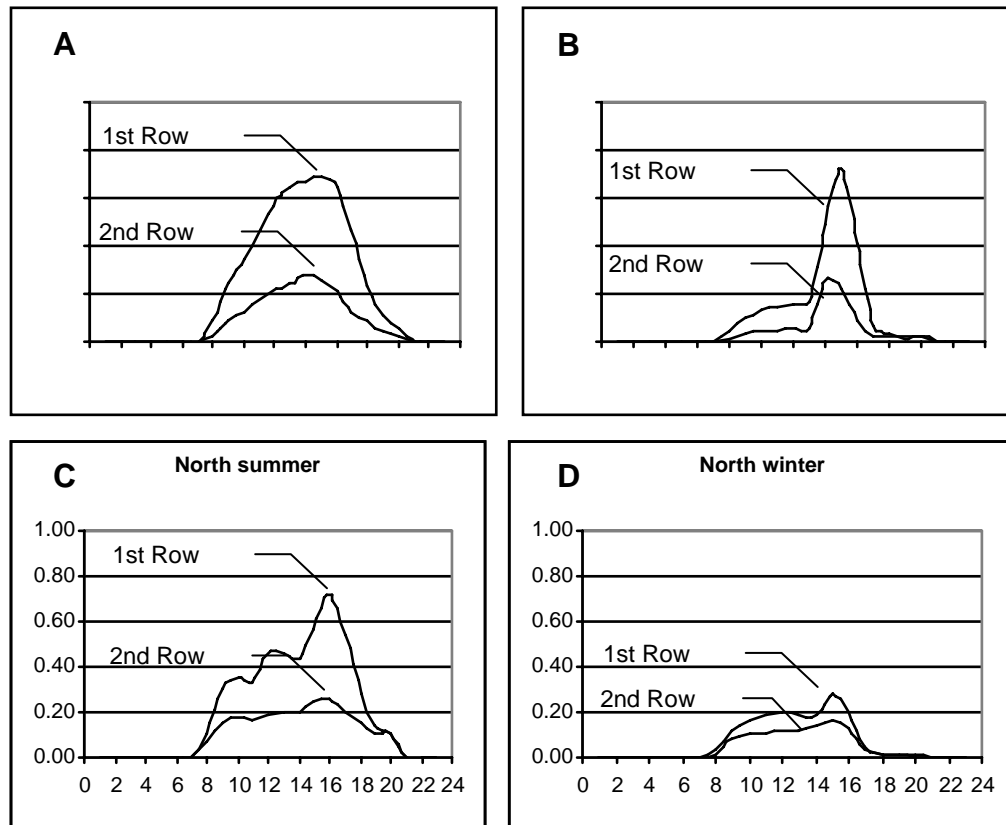


Figure 9. Relative energy savings with daylight dimming as a function of time of day for (A) South Summer, (B) South Winter, (C) North Summer and (D) North Winter for the first and second row of lights from the window. Data based on measured results of daylighting experiments on the 3rd floor of the Federal Building.

Figure 9 shows the relative energy savings for the first and second rows of lights on the South and North sides of the building that we used for calculating energy savings from daylight dimming. As seen in the graphs, energy savings were greater for the south side, and also greater in summer than in winter for both south and north sides. In addition, more total energy was saved during summer “on peak” periods than at any other time during the year. This means that the

daylighting system is saving energy when it is most critical, because electricity costs are highest during these times.

As shown in Figure 10, the total energy savings during June would be approximately 22,000 kWh, which adds up to a cost savings of around \$6,000 per month. These cost savings are attributable primarily to the reduced energy use during on-peak hours and the reduced demand charges. Savings during partial peak hours were modest and assumed to be zero during off-peak hours. Calculated over the entire year, the use of dimming lighting controls throughout the daylight perimeter would save about \$50,000 per year.

Considering that the total annual electricity costs for this building are projected to be approximately \$1.9 million in 2002, the \$50,000 cost savings due to daylighting controls does not appear very significant. However, it should be considered that electric lighting is only one component of the building's electricity costs and only a relatively small percentage of the total floor space (21%) of this building can be effectively daylighted. In a building designed to optimize the use of daylight up to 80% of the total floor area would be available for daylight controls, greatly increasing the electricity savings. Furthermore, the SF Federal Building already uses efficient overhead fluorescent lighting (T-8 lamps with non-dimming electronic ballasts). Given the efficiency of the building baseline (approximately 1.4 watt/ft² for 12 hours/weekday), it is not surprising that even advanced dimming strategies don't have a huge effect on total building electricity usage.

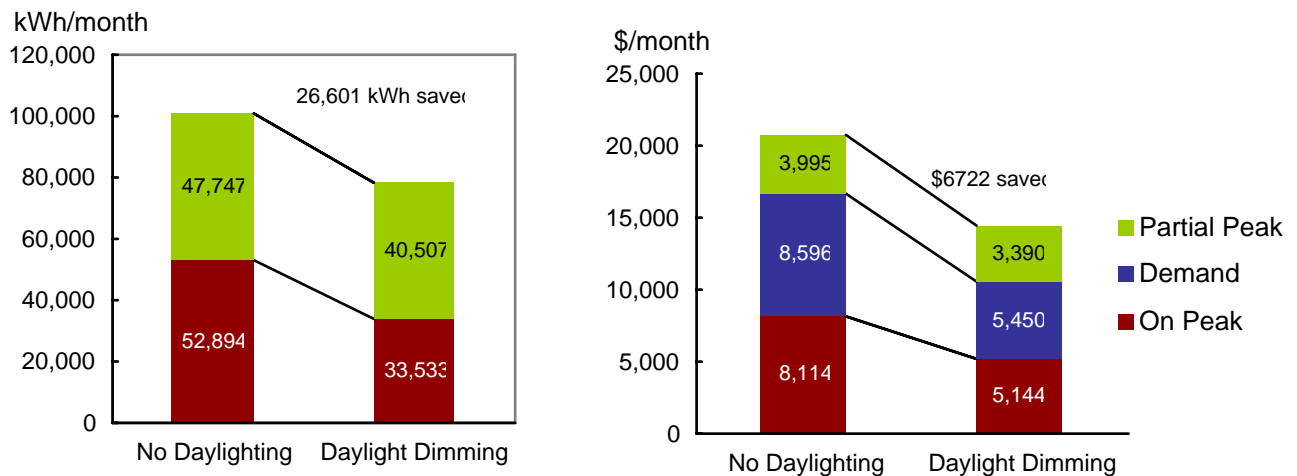


Figure 10. Lighting energy reduction for month of June due to daylight dimming in daylight portions of building for month (left) broken down by time-of-use period. Right figure shows the cost savings for the same month and conditions broken down by demand component and time-of-use period.

Before we can calculate the economic viability of the investment in daylight dimming controls, we need an estimate of the cost to install the controls in a retrofit situation. Since we are installing dimming controls in two floors of the building, we have current values for equipment and labor costs. Applied as a retrofit, the cost of the equipment (dimming ballasts, control wiring, and photocells) will be about $\$0.70/\text{ft}^2$, while the labor cost is about $\$0.90/\text{ft}^2$. Assuming a total cost of $\$1.60/\text{ft}^2$ to retrofit the controls, the simple payback would be 9.5 years. This is too long to be considered economically attractive to most businesses today. However, Government agencies such as GSA can still consider these efficiency upgrades as long as they are life cycle cost-effective over the life of the investment (about 15 years).

In new construction or major renovation applications, the economics for daylight dimming are much more favorable than in the retrofit application we considered at the Federal Building. First, the equipment costs would be much lower since only incremental costs are incurred (the incremental cost is the difference between the dimming ballast cost and the cost of a static ballast that would otherwise be installed). We estimate that the incremental cost of the dimming ballasts and controls would be about $\$0.25/\text{ft}^2$. If the dimming ballasts qualified for utility rebates, the equipment cost could be even lower. Secondly, in new construction, the labor cost to install the dimming ballasts would be zero since the fixtures would be shipped to the job site with the dimming ballasts pre-installed. We estimate that the labor cost to install the control and commissioning could be as low as $\$0.25/\text{ft}^2$. Finally, in a building designed with daylight in mind, the average lighting demand reduction would be about $0.7 \text{ w}/\text{ft}^2$ instead of the $0.4 \text{ watt}/\text{ft}^2$ reduction we calculated for the conventional Federal Building. The simple payback period for such a new building is shown graphically in Figure 11 to be under 2 years. Thus the economic viability of installing daylight dimming controls is much more viable for a building in construction.

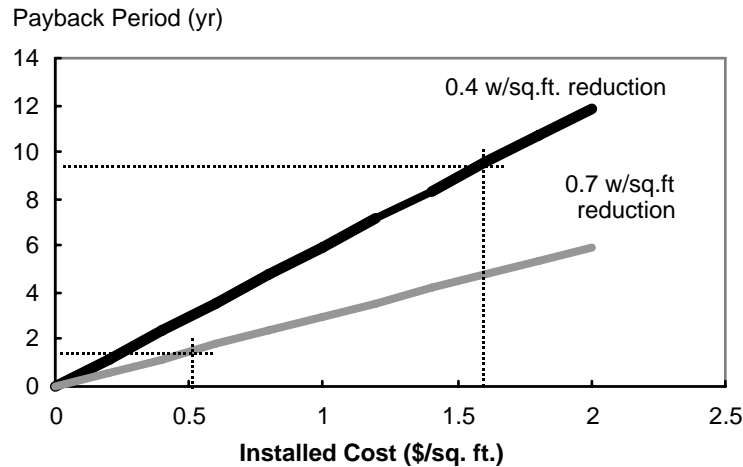


Figure 11. Time to payback the daylight dimming controls for the Federal Building (black line, 0.4 w/ft² reduction) and a new building designed to optimize the use of daylighting (grey line, 0.7 w/ft² reduction). For the Federal building, the installed cost of \$1.60 ft² results in a payback of slightly under 10 years. For a hypothetical new building designed with daylight in mind (grey line), the estimated installed cost of \$0.50/ft² would be paid back in under 2 years.

Conclusion

We investigated the economic effectiveness of installing daylighting controls as a retrofit measure to decrease the electricity demand of a large commercial office building in the San Francisco Bay Area. We found that while the investment would significantly reduce the demand charge and on-peak energy costs, the labor and equipment costs associated with installing daylight dimming controls as a retrofit measure in a conventional large building is only marginally cost effective with today's electricity rates. In a new construction or major renovation application, the economics of daylight dimming is much more attractive, potentially paying back the lighting controls investment in under two years.

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